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Development of a 3D Surface Mapping System to Inspect Capsule Fill-Tube Assemblies used in Laser-Driven Fusion Targets

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INTRODUCTION

Lawrence Livermore National Laboratory is currently working on the National Ignition Campaign (NIC) with the goal of demonstrating inertial confinement fusion (ICF) [1] by generating a thermonuclear ignition and energy gain in a laboratory setting utilizing the National Ignition Facility (NIF) [2].

Figure 1 shows a schematic of the ICF target used in NIC experiments (for a complete description the reader is referred to [3] and [4]). Positioned in the center of the hohlraum is a capsule fill-tube assembly (CFTA) containing the deuterium-tritium (DT) fuel. The CFTA consists of a hollow Ge- or Si-doped plastic fuel capsule ranging in diameter between 2.2 mm and 2.6 mm and an attached 150 μm diameter glass-core fill-tube that tapers down to a 10 μm diameter at the capsule.
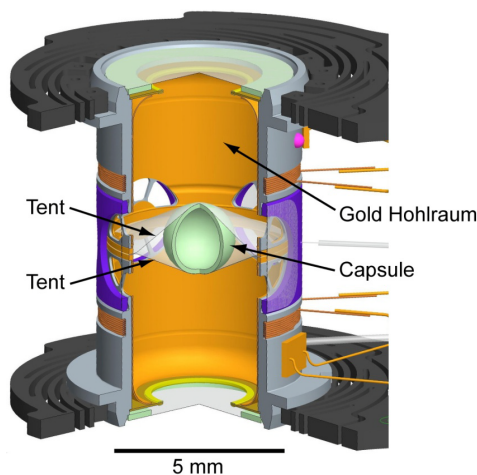

Figure 1: Schematic of the ICF target used in NIC experiments.

The development of a 3D surface mapping system used to measure the surface of a CFTA is presented. The mapping system is an enabling technology to facilitate a quality assurance program and to archive 3D surface information of each CFTA used in fusion ignition experiments. The 3D Surface Mapping System is designed to locate and quantify surface features as small as 50 nm in height and 300 nm in width. Additionally, the system will be calibrated such that the 3D measured surface is related to the capsule angular coordinate system to within 0.25 degree (1σ), which corresponds to approximately 5 μm linear error on the capsule surface.

3D SURFACE MAPPING SYSTEM

The 3D Surface Mapping System, shown in Figure 2 and Figure 3, comprises seven linear and three rotational axes that are used to manipulate the Capsule Fill-Tube Assembly (CFTA) to achieve a deterministic 4π steradian inspection using a surface profiling confocal microscope. To reduce operator error and input effort, the system is fully automated. Automation includes manipulation of the capsule for low magnification image acquisition, data upload, and low magnification image analysis that generates defect coordinates which are in turn used to image at high magnification, providing quantitative height information on a subset of relevant defects.

The primary fixture for handling the CFTA is a vacuum wand mounted to the ϕ-axis stage. The fill-tube is inserted into the inner diameter of the conical tip such that the fill-tube is captured within the wand (basic functionality of the wand is described by Montesanti et.al. [5]). A second
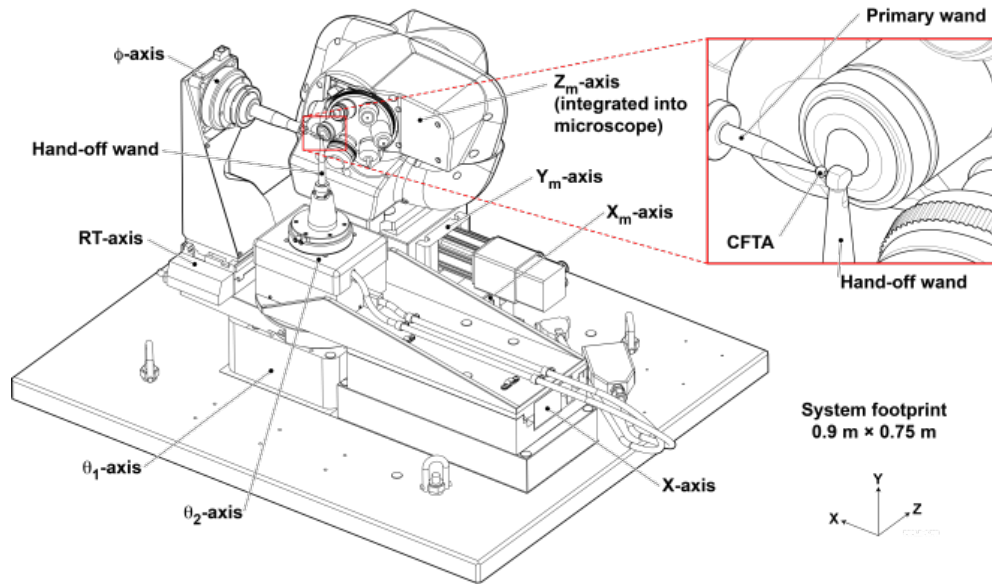
Figure 2: Line diagram of the 3D Mapping System.

vacuum wand, the hand-off wand, will provide the capability of exposing the area initially covered by the primary wand.

MEASUREMENT PRINCIPLE

To obtain a 3D surface map of the capsule, a surface profiling confocal microscope is used. The confocal microscope provides a set of individual images that together form a complete bright field surface map of the capsule. This surface map is performed at a low magnification to reduce measurement time. Higher magnification objectives are then used to investigate individual surface features at a higher fidelity, providing quantitative height information. To achieve this, the ϕ-axis and the θ_1-axis are rotated such that approximately 90% of the capsule surface is covered. Figure 4 shows the geometric coverage pattern at a magnification of 50x (NA = 0.55) producing 460 individual patches in approximately 2.5 hours.

To obtain the remaining surface area, the capsule is transferred from the primary wand to the hand-off wand exposing the area that was previously covered. In order to image the exposed area, the fill-tube is bent utilizing the θ_1-axis, θ_2-axis and RT-axis, see Figure 5. At this point, the remaining surface area is scanned by moving only the microscope (*i.e.* the capsule is held stationary).
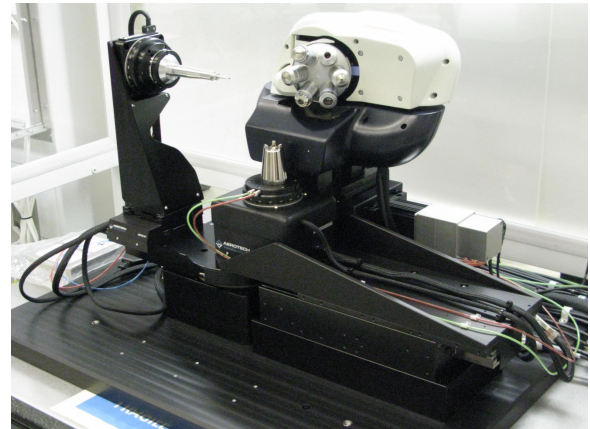

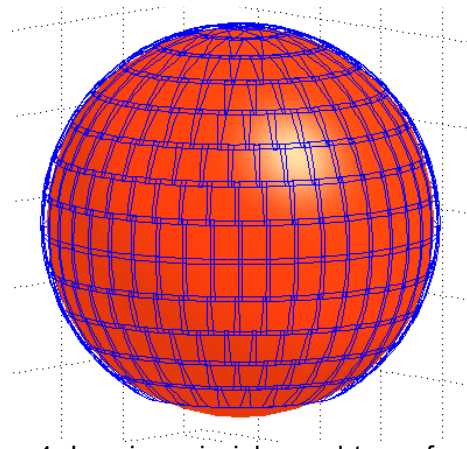Figure 3: Photograph of the 3D Mapping System with the primary wand mounted.

Figure 4: Imaging principle used to perform the measurements of a capsule covering approximately 90% of the surface area.
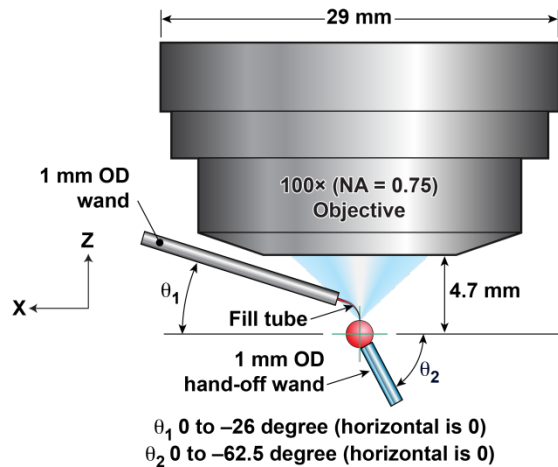
Figure 5: General schematic indicating the bend of the fill-tube and capsule orientation to obtain the remainder of the capsule surface area previously covered by the primary wand.

MEASUREMENT RESULT
Figure 6 shows a 20x confocal image of a spherical test sample, with particulates added to the surface. The inset in Figure 6 is a perspective view of height data from a single particle at 100x magnification.

SUMMARY
An inspection system was developed for ensuring quality assurance and data achieving of a capsule surface used in ICF targets. The system has been automated such that a low magnification map is automatically acquired and analyzed, providing defect coordinates for subsequent high magnification image and topography acquisition. This process currently provides a means of covering 90% of the capsule surface.

In the near term the work will focus on developing the software to provide automated bending of the fill-tube to acquire the remainder of the capsule surface area.
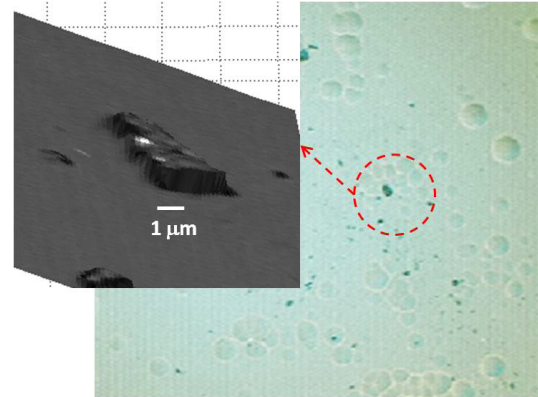

Figure 6: Image patch of a spherical test sample indicating the performance capability of the confocal microscope

ACKNOWLEDGEMENTS

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